# Idea for Location and Detection of Fiber Cuts in PON

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***Abstract*—In this paper, we present an innovative idea to build a software system that allows detecting and locating fiber cuts in Passive Optical Networks (PON) prior to the incident being reported by the customer to the provider' helpdesk. This early detection helps reduce the service restoration time and the number of customer service repair claims.**

***Keywords- PON; OTDR; Fiber cut.***

## I. INTRODUCTION

The idea presented in this paper aims at detecting fiber cuts in advance, accelerating failure resolution, minimizing impacts on the service provision and reducing the number of claims from end customers in a PON [1][2]. We propose to design a software system that generates location information automatically in case a fiber cut occurs. At present, if this happens, users contact the provider's helpdesk, the technicians test the PON in order to find the failure point, and solve the problem on-site. The novelty of this research lies in expecting to detect the fiber cuts before the user's claim occurs, which allows reducing the elapsed time until the problem is solved and improving the customers' perception.

There are works present in the literature that address techniques used to monitor PONs. In [3], Hasegawa et al. propose pulse-Optical Coherence Domain Reflectometry (pulse-OCDR) as a new monitoring method for PONs. The work presents the results of a laboratory demonstration, where reflections from the Fiber Bragg Gratting (FBG) filters installed at the end of drop fibers in a 32-branch PON with a 15 km feeder line are identified with 2.6 cm spatial resolution, and a fault in drop fibers is detected as the absence of one FBG reflection. Although the location of a fault is not implemented because the used OCDR does not detect Rayleigh scattering [4] from the drop fibers, fault detection alone is valuable because it can tell whether the fault is in fiber or in the Optical Network Terminal (ONT) and hence reduces the number of times service personnel is dispatched on troubleshooting. In [4], Costa et al. propose a strategy to monitor the fiber plant failures by implementing an Optical Time Domain Reflectometer (OTDR) subsystem in the physical layer. The procedure is evaluated analyzing its theoretical performance limits.

Our technical solution suggests storing the signal that is reflected back from several points along the fiber in the OTDR to check later against a blueprint when a fiber cut arises. The analysis will allow to detect the cut location and to identify those customers who are impacted by the network failure.

The rest of the paper is organized as follows: Section 2 characterizes the Passive Optical Networks (PON), in Section 3 the Optical Time Domain Reflectometer (OTDR) is described, in Section 4 the method of analysis is presented, and finally in Section 5 we end with some conclusions.

## II. PASSIVE OPTICAL NETWORK

A PON [1][2] is a telecommunications network that employs point-to-multipoint fiber to the premises in which unpowered optical splitters are employed to make possible a single optical fiber to serve multiple premises. A PON includes an Optical Line Terminal (OLT) at the service provider's central office and a number of Optical Network Units (ONU) close to end customers. A PON minimize the amount of fiber and central office equipment required compared with point-to-point architectures. PON technologies: Broadband Optical System Based on a Passive Optical Network (BPON) [6][7][8], Ethernet-Passive-Optical-Network (EPON) [9] and Gigabit Passive Optical Network (GPON) [10][11][12][13] are compared in Table I.

TABLE I. PON TECHNOLOGIES

| Characteristics | BPON | EPON | GPON |
|---|---|---|---|
| Standard | ITU-T G.983.x | IEEE 802.3ah | ITU-T G.984.x |
| Typical Split ratio | 32 | 32 | 64 |
| Typical Max Reach (distance between OLT and ONU) | 20 km | 10 km | 10-20 km |
| OAM | PLOAM | Ethernet OAM | PLOAM |

OAM: Operation, Administration and Maintenance.
PLOAM: Physical Layer Operation, Administration and Maintenance.

## III. OPTICAL TIME DOMAIN REFLECTOMETER

An OTDR is used to test PON, combining a laser source and a high resolution detector to give an inside view of the optical link. This device is connected to the end of the link, the laser source injects a signal into the fiber and the detector

 ISBN: 978-1-61208-432-9 

receives the light reflected from the different connection elements. The main OTDR features are: working wavelength, pulse duration, maximum measured distance, resolution (attenuation or distance), difference between the largest and the smallest value of pulse that can be measured, linearity, i.e., error resulting from nonlinearity ranges over the measured attenuation.

## IV. ALGORITHM

Information about the signal that is reflected back from several points along the fiber wire can be stored by the OTDR to check later against a blueprint when a fiber cut arises. The inspection will allow to detect the cut location and to identify those users who are impacted by the network trouble. A scan should be performed over all network branches that come from the provider's central office in order to detect the failures before users perceive them. We propose a software system (test bed), which includes the following elements:

- A Personal Computer (PC).
- MatLab Tool.
- Algorithm implemented in MatLab Language.
- An OTDR, with functionality to dump data in a format file, which should be understood by MatLab.

An overview of the operation and the procedures carried out by the algorithm are shown in the following sections.

### *A. Main Tasks*

Figure 1 summarizes the main actions that are taken by the algorithm.

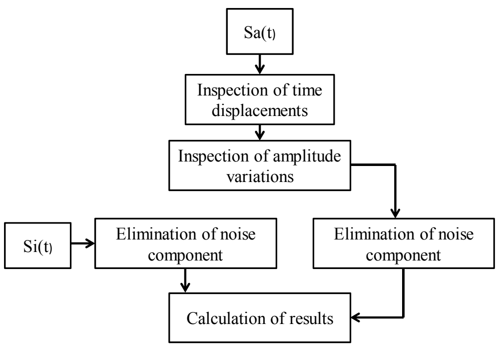


Figure 1. Main Flow Chart.

### *B. Inspection of time displacements*

This procedure detects fluctuations of the signal values collected by the OTDR due to errors in the capture (specifically, time displacement errors). The input signal to this algorithm, Sa (t), is moved in a range D, $-x/2 \leq D \leq x/2$, where x is the window size chosen by the user. Several magnitudes are calculated:

$$Sr(t)=Si(t)-Sa(t+D),\ D \text{ in } [-x/2, x/2] \qquad (1)$$

$$Average(Sr(t)) \qquad (2)$$

The output will be that signal Sfa(t)= Sa(t+D) with the lowest Average (Sr(t)).

Figure 2, shows the obtained averages for one imaginary Sr(t) with x=10.

| t-5 | t-4 | t-3 | t-2 | t-1 | t | t+1 | t+2 | t+3 | t+4 | t+5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4,91 | 4,77 | 4,43 | **1,92** | 4,04 | 3,62 | 4,19 | 4,44 | 4,81 | 5,06 | 5,27 |

Figure 2. Obtained averages for one imaginary Sr(t) with x=10 .

### *C. Inspection of amplitude variations*

This process identifies fluctuations of the signal values collected by the OTDR due to errors in the capture (specifically, amplitude variation errors).

The input signal to this procedure, Sa(t), is moved in a range AR, $-A/2 \leq AR \leq A/2$, where A is the window size chosen by the user.

$$Sr(t)=Si(t)-(Sa(t)+AR),\ AR \text{ in } [-A/2, A/2]$$

$$Average(Sr(t)) \qquad (3)$$

The output will be that signal, Sfa(t)=Sa(t)+ AR, with the lowest Average (Sr(t)).

### *D. Elimination of noise component*

Due to the noise generated in the optical fiber, the signal injected by the OTDR laser source can change significantly until that it is finally captured by the OTDR detector. This procedure eliminates this noise component.

1. In the first step, the slope of the input signal, S(t), is calculated. The following parameters are defined:
   - NS: Number of samples of the S(t), which contain all useful information.
   - W : Window size, which is selected by the user.
   - NW = Total windows (of size W) that are required to include all samples.
   - $A_{HMP}$ = Sfa ($t_{HMP}$), $t_{HMP}$ is the amplitude middle point includes in the highest window (over the total number, NW).
   - $A_{LMP}$ = Sfa ($t_{LMP}$), $t_{LMP}$ is the amplitude middle point in the lowest window (over the total number, NW).
   - $M = (A_{HMP} - A_{LMP})/NS$
2. In the second step, Y(t) = M*t and RS (t) = 2 * (S(t) – Y(t)) are calculated. Figure 3 shows the RS (t) corresponding to one imaginary signal S (t).
3. In the third step, several filters are applied, which allow displaying even clearly the peaks in RS(t).

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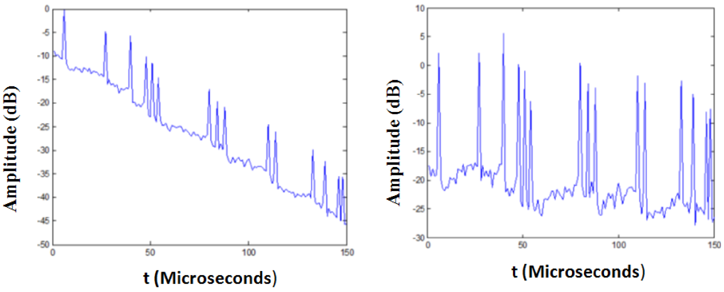



Figure 3. (Left) Imaginary signal S(t). (Right) RS(t) corresponding to S(t).

- Filter 1:

If $RS(t) < A_{HMP} \rightarrow RS(t) = 2 * A_{HMP}$ (4)

- Filter 2:

RS(t) = RS(t) + Absolute value of (Mininum(RS(t))) (5)

- Filter 3:

If $RS(t) < RS(t-1)/2 \rightarrow RS(t) = 0$; (6)
Else RS(t) = RS (t) (7)

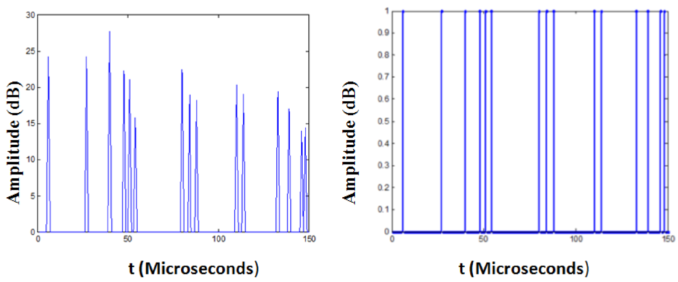



Figure 4. (Left) Imaginary RS(t) after applying the filters 1, 2 and 3. (Right) Imaginary RS(t)•

### *E. Calculation of results*

1. In the first step, this procedure identifies the reflection occurrence, calculating :

If $RS(t) > 0 \rightarrow RS(t)• = 1$ (8)

Figure 4 (Right) shows RS (t)• for one signal imaginary RS(t).

$C_{SfaSi\,(t)} = RS_{Sfa}(t)• – RS_{Si}(t)•$ (9)

Δt where $C_{SfaSi\,(t)} < 0$, t corresponds to the place where a cut happens. Δt where CSfaSi (t) > 0, t refers to the location where the signal is not received due to a cut. Figure 5 shows one imaginary $C_{SfaSi(t)}$ with two peaks (one positive ( t= 88) and other negative ( t=66)).

2. In the second step, this procedure calculates to the provider's central office until the place where the cut occurs, that is:

Distance(Km)=(((Speed of light)*t (Δt where $C_{SfaSi}$ (t)<0)*$10^{-6}$)/2*RI)/1000 (10)

RI: Refraction Index
Speed of light: 3*$10^{8}$ m/second

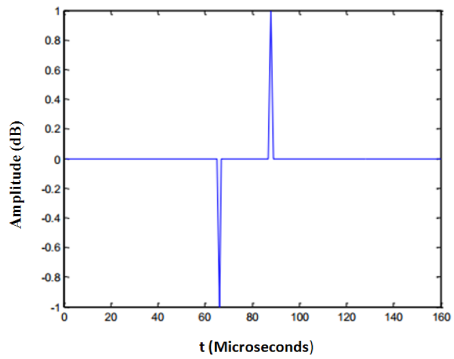
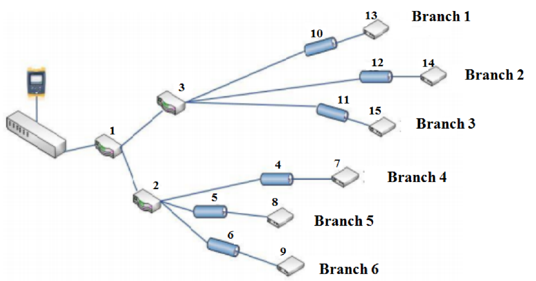



Figure 5. Imaginary CSfaSi (t).

3. In the third step, the specific branch impacted by the cut is identified. The algorithm assumes a PON composes of L levels and B braches. L and B are data provide by the user.
   a. Those values ti where $RS_{Si(ti)} = 1$ are stored in a vector V = {vj}; vj=ti ; j € N. So, for the imaginary signal displayed in Figure 5, V ={6, 27, 40, 48, 51, 54, 80, 84, 88, 110, 114, 133, 139, 146, 148}.
   b. Each value ti where $C_{SfaSi\,(ti)} > 0$ is searched in V, and its position j is deduced. So, for the imaginary signal depicted in the Figure 5 the value 88 is in j= 9.
   c. A matrix A {$a_{lk}$} l<=L; k<=B, where each $a_{lk}$ represents the element position in the PON, is built. The row and column denote the level and the branch where the device is located, respectively.

 ISBN: 978-1-61208-432-9 

Figure 6 shows an imaginary network (in upper part) and its matrix A (in the lower part).




| | Branch 1 | Branch 2 | Branch 3 | Branch 4 | Branch 5 | Branch 6 |
|---|---|---|---|---|---|---|
| Level 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Level 2 | 3 | 3 | 3 | 2 | 2 | 2 |
| Level 3 | 10 | 12 | 11 | 4 | 5 | 6 |
| Level 4 | 13 | 14 | 15 | 7 | 8 | 9 |

Figure 6. (Upper) Imaginary network (Lower) Matrix A corresponding to the network on the upper.

d. Those $a_{lk}$ that are equal to the positions calculated in step a, identify the not-reachable devices. Therefore, the cut must have happened in some preceding section in the PON. So, in the example shown in Figure 7, the not-reachable device is in the level 4 and the branch 6, given that $a_{46} = 9$.

## V. CONCLUSION AND FUTURE WORKS

We have proposed a software system which executes an algorithm to detect and to provide information on the fiber cuts in a PON. Our future works will investigate deeper the method effectiveness (practicality per Signal Noise Rate (SNR)) testing several real scenarios.

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